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Bimanual coordination and aging: Neurobehavioral implications

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ABSTRACT

We investigate whether aging leads to global declines in discrete and continuous bimanual coordination tasks thought to rely on different control mechanisms for temporal coupling of the limbs. All conditions of continuous bimanual circle drawing were associated with age-equivalent temporal control. This was also true for discrete simultaneous tapping. Older adults' between-hand coordination deficits were specific to discrete tapping conditions requiring asynchronous intermanual timing and were associated with self-reported executive dysfunction on the Dysexecutive (DEX) questionnaire. Also, older adults exclusively showed a relationship between the most difficult bimanual circling condition and a measure of working memory. Thus, age-related changes in bimanual coordination are specific to task conditions that place complex timing demands on left and right hand movements and are, therefore, likely to require executive control.

1. Introduction

Many everyday tasks such as feeding and dressing oneself rely on bimanual coordination. Age-related declines in coordination depend on the type and rate of bimanual performance (Greene & Williams, 1996; Seidler, Alberts, & Stelmach, 2002; Serrien, Swinnen, & Stelmach, 2000; Stelmach, Amrhein, & Goggin, 1988; Swinnen et al., 1998). For example, when aiming at near or far targets, older and younger adults were more accurate for symmetrical (e.g. both hands move to equi-distant targets) than asymmetrical movements (e.g. one hand moves to a near target while the other moves to a far target). Nevertheless, older adults showed more breakdowns in temporal coordination and slower movement execution times than younger adults, especially in the asymmetric condition (Stelmach et al., 1988). Similarly, for bimanual arm or wrist extensions and flexions in the horizontal plane (e.g. perpendicular to the vertical axis of the body) older adults moved more slowly and exhibited more phase shifts back to mirror-symmetric coordination in asymmetric conditions, especially as the required movement rate increased. Thus, older adults have difficulty coordinating asymmetric movements at high speeds and are more susceptible to shifts towards preferred coordination modes than younger adults (Greene & Williams, 1996; Lee, Wishart, & Murdoch, 2002; Serrien, Teasdale, Bard, & Fleury, 1996; Swinnen et al., 1998; Wishart, Lee, Murdoch, & Hodges, 2000). However, it is not clear to what degree age-related changes are systematic across bimanual coordination tasks thought to rely on different mechanisms to achieve temporal coupling between the limbs.

Work has shown that the event structure of bimanual movements may determine the mechanisms engaged to achieve inter-limb temporal coordination. A distinction has been drawn between movements which are discrete, with an explicit pause or landmark between each movement, and those which are continuous, with no pause between motor events (Ivry, Spencer, Zelaznik, & Diedrichsen, 2002; Kennerley, Diedrichsen, Hazeltine, Semjen, & Ivry, 2002; Robertson et al., 1999). In particular, research with patients who have undergone full corpus callosum (CC) resection shows intact intermanual coupling for discrete, repetitive bimanual tasks but temporal decoupling for simultaneous movements of the hands or fingers during continuous tasks, implicating a role for the CC in control of the latter (Helmuth & Ivry, 1996; Ivry & Hazeltine, 1999; Kennerley et al., 2002). The fact that for synchronous discrete tapping these patients, like healthy controls, maintain inter-limb temporal coupling and exhibit reduced within-hand variability when compared to unimanual tapping – known as the "bimanual advantage" – implies that discrete bimanual coordination may rely on subcortical mechanisms (Helmuth & Ivry, 1996; Ivry & Hazeltine, 1999). However, as complexity of the between-hand temporal constraints of discrete movements increases, coordination may rely

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Table 1
Demographics and neuropsychological measures.

Demographic measure/neuropsychological test	Targeted functions	Young adults	Older adults	*d*
Education**		13.88 (1.17)	16.12 (2.20)	1.27
Handedness*		.75 (.16)	.86 (.13)	.75
Hours/week of exercise		7.18 (4.08)	8.47 (8.85)	.19
Hours/week instrument practice		1.32 (2.60)	.49 (1.3)	.40
Hours/week typing*		8.15 (5.30)	3.88 (4.92)	.84
Mini-Mental State Exam	General cognitive function	29.59 (.62)	29.06 (1.09)	.60
DEX	Executive functions	21.00 (8.77)	18.53 (8.74)	.28
Digit symbol***	Sensorimotor processing speed	96.06 (12.13)	68.00 (13.19)	2.21
Forward digit span*	Verbal working memory	12.65 (1.58)	11.06 (2.56)	.75
Backward digit span	Verbal working memory	8.88 (2.32)	8.00 (2.37)	.38
Reading span* (# items remembered)	Verbal working memory	31.71 (4.73)	27.47 (5.87)	.80
Trails A & B* (difference score—seconds)	Set switching; executive functions	24.00 (17.09)	37.00 (15.69)	.79
STROOP***	Response inhibition	19.12 (7.78)	28.53 (6.39)	1.32
WAIS vocabulary	Semantic memory	50.24 (7.42)	53.76 (5.49)	.54

Note: Reported values are the means for each group. Standard deviation scores are shown in parentheses. Cohen's *d* is reported as the measure of effect size. The neuropsychological tests include the Edinburgh Handedness Inventory (Oldfield, 1971), the Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975), reading span (Daneman & Carpenter, 1980), the Trail-Making A & B task from the Halstead-Reitan test battery (Reitan & Wolfson, 1985), the vocabulary, digit-symbol substitution, forward digit span, and backward digit span tasks from the WAIS-R (Wechsler, 1981), the Stroop task (Stroop, 1935), and the DEX (dysexecutive syndrome) questionnaire (Wilson, Evans, & Emslie, 1996).

* $p < .05$.
** $p < .01$.
*** $p < .001$.

more on interhemispheric control (Stančák, Cohen, Seidler, Duong, & Kim, 2003).

The current study examines whether aging leads to specific or global changes across coordination tasks with different event structures. Participants performed continuous bimanual circle-drawing as well as a discrete tapping task with unimanual, simultaneous bimanual, and asynchronous bimanual conditions. To the extent that normal aging compromises one source of bimanual control over another, we should see specific declines on associated bimanual coordination conditions. Indeed, evidence showing that aging is linked to decreased size and integrity of the CC (Bartzokis et al., 2004; Head et al., 2004; Sullivan, Pfefferbaum, Adalsteinsson, Swan, & Carmelli, 2002; however, see Driesen & Raz, 1995; Raz, 2000) suggests that we may find specific declines in continuous bimanual circling, which relies on the CC for inter-limb temporal coordination (Kennerley et al., 2002). Alternatively, aging may lead to deterioration in some common factor such as processing speed (Salthouse, 1996) or inhibitory control (Hasher & Zacks, 1988) that subsequently results in global declines across bimanual coordination tasks. This possibility is supported by demonstrations of increased correlations among diverse sensorimotor and cognitive tasks with increasing age (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1997). If a global process is at work, we expect age-related impairments across both types of bimanual coordination, even in less demanding conditions (e.g. simultaneous and unimanual tapping). Additionally, older adults should show increased inter-task correlations between bimanual coordination measures and with neuropsychological assessments compared to younger adults.

2. Methods

2.1. Participants

The study protocol and consent were approved by the University of Michigan Institutional Review Board and conformed to the ethical standards of the 1964 Declaration of Helsinki. Seventeen older ($M = 72.53 \pm 3.79$ years; 9 females) and seventeen younger ($M = 20.18 \pm 1.13$ years; 7 females) adults gave informed consent and were paid for their participation. Participants on medication for osteoarthritis or arthrosis reported no problems moving their fingers and arms.

2.2. Procedure

Participants completed two, 2.5–3 h testing sessions, not more than a week apart. The first involved neuropsychological tests (see Table 1 for targeted functions), health questionnaires and continuous circle-drawing. Discrete tapping was performed in session 2. Motor tasks were implemented via custom programs in Labview 6.1 and were administered on a Dell Optiplex GX150 computer. Inclusion criteria were right-handedness and a minimum MMSE score of 27.

2.2.1. Continuous circle-drawing

Participants drew circles (maximum diameter of ∼6 cm) using two dual-potentiometer joysticks positioned 10 in. in front of them and aligned with the shoulders. Arm rests limited movements to the wrists and fingers. Participants completed four conditions at their self-determined preferred and maximum circling rates. Two were mirror-symmetric where one hand circled clockwise and the other counter-clockwise, and two were asymmetric, where the hands circled in the same direction. On each trial participants circled continuously for 15 s while keeping their hands synchronized. There were three blocks of trials for each condition, with block order pseudo-randomized—a full block of each condition, with three trials each of preferred and maximum speed circling, was completed before any were repeated. Data were sampled at a rate of 1000 Hz and smoothed with a Butterworth low pass filter with a cut-off frequency of 10 Hz. Participants were not given practice or feedback.

2.2.2. Discrete, repetitive finger tapping

Participants tapped with their index fingers in the following conditions:

(1) Right hand only (unimanual); R.
(2) Left hand only (unimanual); L.
(3) Simultaneous (0 ms lag; bimanual); Sim.
(4) Right-leads-left (180 ms lag; bimanual); RL.
(5) Left-leads-right (180 ms lag, bimanual); LR.

Five, 30-second trials of each condition were completed at three inter-tap intervals (ITI): 800 ms (fast), 1000 ms (medium), and 1200 ms (slow), randomized across run order. Participants pressed buttons on response boxes 10 in. in front of them. On each trial, they fixated on a point centered in an 11.5 cm × 11.5 cm white display box on the computer screen. Green circles (∼13 mm diameter) flashed 2 cm from either side of fixation at the given ITI to pace participants; side of presentation corresponded with tapping hand.

A trial was valid if each tap fell within the target ITI ±300 ms. Invalid trials were repeated up to 3 times. Approximately 4% of younger and 18% of older adults' trials were invalid.[1] One older adult with no valid LR trials was omitted from the tapping analyses. Though not given practice, participants received within-hand feedback after each trial.

2.3. Data analysis

For circling, we calculated average rate and average absolute lag between hands using data from the longest period of each trial with no changes in direction or

[1] An analysis of the number of invalid trials in this task showed that older adults had significantly more invalid trials than younger adults, especially for asynchronous conditions.